Patients with a Normal Pressure Hydrocephalus Shunt Have Fewer Complications than Do Patients with Other Shunts

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Abstract: BACKGROUND Ventriculoperitoneal (VP) shunting is a well-established therapy for hydrocephalus. However, complications are frequent. The incidence of idiopathic normal pressure hydrocephalus (NPH) increases with the aging of the population. We evaluated the functional status of patients and the classification of complications associated with VP shunt procedures in our center. METHODS We recorded all VP shunt procedures in our prospective patient registry from January 2013 to December 2015. Functional outcome (Karnofsky Performance Status [KPS] and modified Rankin Scale) and complications were compiled from patient records. Any deviation from the normal postoperative course within 3 months after surgery was considered a complication. Complications were classified with the therapy-oriented Clavien-Dindo grading system. We evaluated potential risk factors with a logistic regression model. RESULTS From 285 procedures in the reporting period, 90 were excluded, resulting in 195 patients. Among those patients, 174 (90%) were shunt implantations and 21 (11%) were shunt revisions. Forty-four shunts (23%) were implanted for NPH. Median KPS improved over the first year after surgery. Although some type of complication was observed in 114 patients (58%), 60 of those complications (31%) did not require surgical treatment (Clavien-Dindo grade <3). In 50 patients (26%), the complication concerned the shunt itself. A high KPS at admission and NPH as underlying indication significantly reduced the odds ratio for a complication. CONCLUSIONS Although shunt surgery has a high general rate of complications, this rate is significantly lower for patients with NPH. The decision for shunting in patients with NPH should consider the low complication rate specific for the group of patients with NPH.

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Normal pressure hydrocephalus shunt patients have fewer complications than other shunt patients.

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Abstract

Background: Ventriculoperitoneal (VP) shunting is a well-established therapy for hydrocephalus. However, complications are frequent. The incidence of idiopathic normal pressure hydrocephalus (NPH) rises with the aging of the population. We evaluated the functional status of patients and the classification of complications associated with VP shunt procedures in our center.

Methods: We recorded all VP-shunt procedures in our prospective patient registry from January 2013 to December 2015. Functional outcome (KPS and mRS) and complications were compiled from patient records. Any deviation from the normal postoperative course within 3 months after surgery was considered a complication. Complications were classified with the therapy-oriented Clavien-Dindo classification system (CDG). We evaluated potential risk factors with a logistic regression model.

Results: From 285 procedures in the reporting period, 90 were excluded, resulting in 195 cases. Among those, 174 (90%) were shunt implantations and 21 (11%) were shunt revisions. 44 shunts (23%) were implanted for NPH. Median KPS improved over the first year after surgery. While any type of complication was observed in 114 cases (58%), 60 (31%) of those complications did not require surgical treatment (CDG <3). In 50 cases (26%) the complication concerned the shunt itself. A high KPS at admission and NPH as underlying indication significantly reduced the odds ratio for a complication.

Conclusion: While shunt surgery has a high general rate of complications, this rate is significantly lower for NPH patients. The decision for shunting in NPH patients should consider the low complication rate specific for the NPH patient group.

Introduction

Cerebrospinal fluid (CSF) diversion is a well-established therapy to treat various causes of hydrocephalus. Idiopathic normal pressure hydrocephalus (NPH) is considered a primary form of hydrocephalus and one of the few curable causes of dementia. Secondary forms of hydrocephalus comprise malresorptive hydrocephalus, e.g. following subarachnoid or intraventricular hemorrhage, trauma and infections, or occlusive hydrocephalus in the context of mass lesions, aqueductal stenosis and tumors (1). The three most common causes in adults are NPH, malresorptive hydrocephalus and occlusive hydrocephalus (2, 3).

Both primary and secondary causes of hydrocephalus are commonly treated with a CSF shunt (1, 2, 4). Cerebrospinal fluid shunts have been used for more than 50 years. For secondary forms of hydrocephalus CSF diversion can be life-saving, while dramatically reducing morbidity in patients suffering from NPH (2). In roughly 74% of NPH patients, CSF shunting results in significant improvement of clinical symptoms (1, 5, 6).

Still, complications in CSF shunt procedures are common and a significant cause of morbidity. As seen in studies with sufficiently long follow-up after primary shunting, more than half of patients require one or multiple shunt revision procedures (7). Complications are usually due to dysfunctions of the catheter, rather than related to the surgical intervention, which is a short and simple procedure (8). The most common complications are mechanical dysfunctions and infections. In a previous study, the rate of mechanical shunt malfunctions requiring a secondary intervention was 41%, and 7% of cases developed a shunt infection (2).

We hereby report a study on patients with hydrocephalus who underwent CSF shunting in our department. We were interested to analyze how the functional outcome and the complications differed between patients suffering from a NPH and patients suffering from other forms of hydrocephalus. We graded complications by a therapy-oriented classification scheme (9). We evaluated factors associated with an increased probability for complications of shunt-related procedures. The ultimate aim was to identify patients with a particularly high or low risk of complications following CSF shunting.

Methods

The patient registry

Our department has established a method of recording patient data, including outcome parameters and complications, following a strict protocol in a patient registry (10). Demographic and clinical data are collected prospectively in electronic case report forms (eCRFs) at admission, after surgery, at discharge, and at each follow-up visit. In case of missing data, the forms were completed with information from the electronic patient records. Clinical data include the Karnofsky Performance Status Scale (KPS) and the modified Rankin Scale (mRS). Demographic data include age, sex, and source of admission, i.e. the place of residence before hospitalization.

Patient selection criteria

For this study, we retrieved records for all cases having received a shunt from January 2013 to December 2015. We excluded those shunt revisions where the shunt system was implanted before our reporting period or in another hospital.

Cases were categorized into the three diagnosis related groups: 1) NPH, 2) other forms of hydrocephalus (e.g., malresorptive or occlusive hydrocephalus), and 3) shunt revision. A shunt revision was only treated as a separate case if the revision surgery took place in a later hospital stay than the original shunt implantation, otherwise the revision was treated as a direct complication of the first intervention. Follow-up was defined as the time from the first surgery until the last consultation.

Interventions

The standard treatment of hydrocephalus in our clinic is the implantation of a ventriculoperitoneal (VP) shunt. Most of the implanted shunts had an additional gravitational valve to reduce the incidence of overdrainage events (6). If a shunt revision was needed, the shunt was replaced either in part or in total.

Before surgery, patients were scanned for symptoms of infection using Overturf's criteria (vomiting, fever, central nervous system dysfunctions and CSF leukocytosis) (11).

During surgery, antibiotic prophylaxis (Cefazolin 1.5g i.v. single dose) was given to every patient 30 minutes before skin incision.

After surgery, the patient was transferred to the intensive care unit (ICU) and to the ward after unremarkable awakening from anesthesia. Depending on their clinical condition, patients were discharged to a rehabilitation clinic, to their routine surroundings (home) or other places such as another hospital or a nursing home.

Complications

Any deviation from the normal postoperative course within three months after the intervention was defined as a complication. Sequelae and failure to cure were not counted as complications. The perioperative period included 30 days after surgery, which is common practice in our hospital. Since some complications (e.g. wound infections) arise during surgery or during the postoperative period but are only detected later, the reporting period for complications was extended to three months.

Symptomatic complications concerning the shunt system were grouped into the categories overdrainage, underdrainage, infection, obstruction, abdominal dislocation or disconnection of the catheter.

All complications were classified in the therapy-oriented Clavien-Dindo classification system (CDG), which considers the therapy needed to treat the complication (9, 12):

- CDG-1 includes any deviation from the normal postoperative course without the need of a pharmacological or surgical therapy. With this wide definition, our complication rate is rather high but we avoid underreporting.
- For CDG-2 complications only pharmacological treatment is required.
- Complications necessitating surgical interventions are graded CDG-3a (without general anesthesia) or CDG-3b (under general anesthesia).
- If a complication is life-threatening and/or requires treatment in the intensive care unit (ICU), grades are CDG-4a (single-organ dysfunction) or CDG-4b (multi-organ dysfunctions), respectively.
- The patient's death within the perioperative period (i.e. until 30 days after surgery) is rated as CDG-5.

If several complications occurred in one case, for ease of handling, we only report the highest CDG.

Statistics

A descriptive analysis was performed for all relevant variables and to illustrate the unadjusted relationship between the potential predictors and the outcome "complication". To model the relationship between the binary outcome and the potential predictors we have used two completely different model approaches – a logistic regression model and a random forest (RF) classifier (13). The logistic

regression results are only valid if some model assumptions are fulfilled, which we check by performing a residual analysis and by performing a global test of goodness of fit (le Cessie – van Houwelingen – Copas – Hosmer weighted sum of squares test). To get unbiased estimates we need approximately ten times more events than estimated coefficients in the regression model. Since only 114 patients with complication and 81 patients without complications were observed, we were limited in the complexity of the model (with less than ten coefficients). Opposed to the logistic regression model, a RF can handle situations with more predictors than observations. Moreover, a RF intrinsically allows for interactions and non-linearity and has only very weak model assumptions. We compared both models to judge whether the logistic regression model was already sufficient to fit the data. Confidence intervals (CI) at the 95% level were calculated where appropriate using the Wilson Method. All analyses regarding the model were performed with R - a language and environment for statistical computing (13).

Ethics

The study protocol was approved upfront by the local ethics review board (Kantonale Ethikkommission KEK-ZH 2012-0244). The authors have no relevant conflicts of interest.

Results

Patient group

A total of 285 shunt-related procedures were performed in our unit during the reporting period (Figure 1). We excluded 90 interventions of revisions of shunts implanted in another hospital or revisions from shunts, which were implemented before the reporting period. We also excluded all children receiving a shunt system from our study. The final study cohort thus consisted of 195 cases (median age 62 years, range 22-87y, 52% men). Among them, 174 (174/195, 90%) were shunt implantations and 21 (21/195, 11%) were shunt revisions. The indication for shunt placement was NPH (44 cases) and malresorptive or occlusive hydrocephalus (other hydrocephalus, 130 cases). In these patients, the shunt was implanted following subarachnoid or intracranial hemorrhage (68 cases), traumatic brain injury (TBI, 15 cases), tumors (36 cases), and other indications (11 cases). The age of the NPH patient group was closely distributed around the median of 75y (range 57y – 86y, Figure 2), while the age of other hydrocephalus patients ranged broadly from 22-87y (median 55y).

Patient status

Clinical status scales

The level of functional capacity improved over the reporting period both for patients with a complication (brown) and for those without a complication (green) until three to six months after shunt surgery (Figure 3).

Median KPS improved from 50% at admission to 70% at three months and to 80% after six months. The median mRS improved from 4 at admission to 3 at discharge and to 2 at three and six months.

At each assessment, the median KPS was higher in cases in which no complication occurred compared to cases in which a complication occurred within three months. Patients experiencing a complication had a worse median KPS and mRS score already at admission. Similarly, the rate of previous surgery was 67% for those experiencing a complication, while the rate was only 45% in patients without a complication.

Place of residence

The most common place of residence before surgery was routine surroundings (home) for both patients without (52/81, 64%) and those with a complication (65/114, 57%). The proportion of patients transferred to our institution from another hospital was higher in those experiencing a complication (29/114, 25%), compared to those with an uneventful course (6/81, 7%, chi2-test p-value = 0.0023). Patients without any complication were discharged to their routine surroundings (home) in most cases (42/81, 52%), whereas those experiencing a complication were more frequently discharged to in-patient rehabilitation (70/114, 61%).

Indication

Across all patients, complications occurred in 92 cases (47%) until discharge and in 114 cases (58%) at the three months follow up. When distinguishing between the indications for surgery, the complication rate was lower for NPH patients (16/44, 36%) as compared to the other indications (90/130, 69%, chi2-test p-value = 0.0002) (Figure 4).

The most common types of complications are listed in Figure 5, again distinguishing between NPH patients and other indications. Complications concerning the shunt itself were most frequent (50 cases, 26%) and of these 30 (15%) required a shunt revision. Other frequent complications were pneumonia in 36 cases (18%), urinary tract infection in 25 (13%) and epileptic seizure in 20 cases (10%), which were rare for NPH patients (Figure 5). In 19 (10%) cases an infection such as meningitis, ventriculitis or another infection of the CSF occurred. Some patients had multiple complications.

Classification of complications

The majority of complications required pharmaceutical treatment only (CDG-2; 46/195 cases, 24%, Table 1). Five patients died within 30 days after shunting (CDG-5; 3%). The overall mortality rate was 7% (14/195) during our 3-month reporting period.

The distribution of the CDG grades of NPH and other hydrocephalus patients are presented in Figure 6.

Figure 7A shows the CDG distribution of the 92 cases with complications registered at discharge (total complication rate: 47%, 95%-CI [40% 54%]). The majority of complications (56/92 = 61%, 95%-CI [50% 71%]) were treated without invasive treatment (CDG-1 and CDG-2).

The median postoperative length of hospitalization was significantly higher in cases with a complication at discharge (9 vs. 4 days, p-value < 0.001, Mann-Whitney U-test). The length of stay and the CDG grade were correlated with Spearman's rho=0.46 (p-value = 0.001) and the linear fit had a slope of 2.5 days per increment of CDG (Figure 7B).

The KPS at discharge decreased with the CDG grade of the complication (Figure 7C). The KPS and the CDG grade were correlated with Spearman's rho=-0.48 (p-value < 0.001) and the linear fit had a slope of -7.9 KPS points per increment of CDG. The median KPS at discharge was higher without than with a complication (75 vs. 40, p-value < 0.001, Mann-Whitney U-test).

Shunt-related complications

The most common shunt-related complications were overdrainage and infection, followed by abdominal dislocation, obstruction, underdrainage and disconnection (Table 2). Overdrainage was defined as reduction of the ICP to a level below the intended, leading to typical symptoms like headache and nausea or even to development of hygroma or chronic subdural hematoma. Underdrainage on the other hand was defined as insufficient drainage in absence of shunt-malfunction, leading to enlargement of ventricles, symptoms of hydrocephalus or insufficient resolving of the underlying disorder's symptoms. Infection comprises ventriculitis, meningitis, wound infections and colonization of the implanted material. Obstruction was defined as a condition leading to a high flow-resistance of the shunt system due to reduction of its diameter or mechanical problems. In abdominal dislocation, the catheter is either not implanted in the intraperitoneal cavity correctly or dislocates from there to a compartment in the subcutaneous tissue for various, mostly unknown, reasons. Disconnections were disturbances of the shunt's continuity, either by loosening of the catheter from the shunt valve or by rupture of the catheter due to weaknesses of the material.

Of a total of 50 shunt problems recorded at admission, discharge or follow-up, overdrainage was seen in 20 (10%) cases, of which in five cases a hygroma, in three cases a chronic subdural hematoma and in three cases a sinking skin flap syndrome

253 occurred. In only four (2%) of all cases with overdrainage the underlying etiology was
254 NPH. Most cases with overdrainage (11/20, 55%) only needed an adjustment of the
255 valve as therapy and were therefore graded CDG-1. Underdrainage was most often
256 graded as CDG-1 as well, unlike all other shunt-related complications. Abdominal
257 dislocation, infection and obstruction usually required revision surgery (CDG-3b).

258 Shunt infection was seen in 9 cases, two of which occurred secondary after
259 extracranial procedures or infections, and four infections were subsequent to wound
260 dehiscence. When comparing between groups, only one NPH patient had an
261 infection (1/44, 2%) compared to 9 (9/130, 7%) patients having received shunts for
262 other indications (Fisher exact test p-value = 0.45).

263 ***Logistic regression model***

264 With our five explanatory variables, from which three are factor variables with two or
265 three levels, we need to estimate eight coefficients if no interactions are included in
266 the model. Since we only have 81 patients without a complication we cannot afford to
267 fit a logistic regression including interaction terms. The fitted logistic regression
268 model does not violate the model assumptions and is summarized in table 3 by the
269 estimated odds ratios (OR) and the range of the corresponding 95% confidence
270 intervals along with the p-value. As predictors we selected five main parameters,
271 where clinical experience led us to assume a possible effect on the risk of
272 complications. The adjusted associations between the predictors and the outcome
273 are in concordance with the unadjusted associations that we have observed in the
274 descriptive analysis. All following statements about the association of the different
275 predictors and the risk for complication are valid for the situation where we adjust for
276 all other predictors included in the model.

Age: There is no evidence for an association with the risk for a complication.
Indication for surgery: The risk for a complication in a NPH patient is only 31% as high as compared to a patient receiving a shunt for a different indication. We are 95% confident that this value lies between 13 – 76% (p=0.011). A chi-square-test confirmed that a model including the variable “indication for surgery” fits the data significantly better than a model without this variable, p-value = 0.03.
Sex: There is no evidence for an association with the risk for a complication.
Source of admission: There is evidence for an association with the risk for complication – especially “other care”, which mostly includes nursing home and rehabilitation clinic, is associated with lower risk (only 35% as high). A Chi-square-test confirmed that a model including the variable “source of admission” fits the data significantly better than a model without this variable, p-value = 0.02.
KPS: For every one-step increase in the KPS score at admission, the risk to experience a complication is about 3% lower (OR 0.97, 95% CI 0.96 – 0.99, p=0.001; also confirmed via chi-square-test, p-value = 0.0006).

Since the fitted logistic regression model does not allow for interactions and non-linear associations, we have also fitted a more flexible RF model to our data which revealed partial dependencies between the predictors and the complication risk that are in concordance with the results from the logistic regression (data not shown). Confirming the results with the RF model indicates that results of the logistic regression model are valid.

Discussion

In 1935, Wilder Penfield stated “all surgeons who continue to face the hydrocephalus problem require the support of fortified optimism“(14). Fortunately, today we have advanced quite a bit from there, but nonetheless, hydrocephalus treatment remains challenging in a relevant share of the cases and CSF shunts are still known to be prone to complications. While technical problems with shunts may principally affect all patients, in some indications for CSF shunts complications are more likely. Patients with normal pressure hydrocephalus (NPH) can easily be separated from other shunt-indications, as they don’t suffer from an acute disorder like a recent intracranial bleeding and are of a relatively homogenous age. Our patient registry allows us to analyze the complication rates of CSF shunts at our institute and at the same time distinguish between NPH patients and others for the sake of a better understanding of the patient groups’ individual risk profiles.

In our study, we made a direct comparison between shunting procedures for NPH patients, patients with other indications for CSF shunts, and shunt revisions. In general, we found the expected high rate of complications (60%) after CSF shunt procedures, where a complication was defined as any deviation from the uneventful postoperative course within 3 months after surgery. While complications of the shunt system itself were most frequent across all patients, the rate of other complications, and in particular the rate of shunt infections, was significantly lower in NPH patients.

Shunt-related complications

The most common adverse events at admission, discharge and after 3 months were complications concerning the shunt itself. This result corresponds with a publication about hydrokinetic problems of shunting, that finds complications usually related to

dysfunctions of the catheter, rather than due to the surgical intervention, which is a short and simple procedure (8).

Shunt dysfunctions can be classified into six categories: overdrainage, underdrainage, infection, abdominal dislocation, obstruction and disconnection of the catheter. Overdrainage and infection are the most common complications found in our series. Due to these events, the hydrocephalus was not resolved and further treatment was necessary.

Overdrainage, as the most common shunt-related complication, occurred in 15% of all cases and was equally frequent for NPH and other indications. This rate is consistent with a study about the hydrokinetic parameters of shunts, which shows that shunting induces unavoidable and drastic differences in intraventricular hydrokinetic pressure and CSF drainage. A perfect shunt needs to comply with the CSF production, which is the only constant parameter at a rate of 0.35 ml/min (8).

Infection of the shunt system occurred in 13% of all cases. In the literature, different studies use different definitions of a shunt, which results in a wide spread of infection rates (2, 7, 15, 16). We here used Overturf's criteria, characterized by typical clinical symptoms and signs such as vomiting, fever, central nervous system dysfunctions and CSF leukocytosis. Those may vary by the site of infection, the type of pathogen and the time of outbreak after the shunt placement (11). The number of infections is probably overestimated with this definition because of the possible contamination with skin flora at the time of surgical removal (17). Still, our infection rate is in the middle of the range reported in the literature (1, 6, 13, 14). As an interesting observation, albeit not reaching statistical significance, among all cases with shunt infection, there was only one NPH patient, leading to a very low infection rate of 2% for the NPH group.

Shunt revisions occur at a rate of 24% in the literature (1, 2), therefore our overall rate of 15% is at the lower end of this range.

Classification of complications

Across all complications, most frequent were grades CDG-1 and CDG-2, i.e. the complication, which could be treated without surgical intervention (Figure 6). Among the frequent shunt-related complications, for overdrainage either the valve was adjusted (CDG-1) or the shunt needed revision (CDG-3b). When comparing NPH and other hydrocephalus indications, the rate of complications for each CDG grade was lower or equal for the NPH patient group (Figure 6).

With increasing CDG the number of days spent in hospital increased also (Figure 7B), which reflects the design of the therapy-oriented classification system. Likewise, an increase of CDG correlated with a decrease of KPS at discharge (Figure 7C). This is not trivial. For example in tumor surgery, an infarction of tissue in an eloquent area that does not require pharmaceutical or surgical treatment will only be graded as CDG-1 while a neurological deficit due to this complication might well be very severe and result in a low KPS. As another frequent example in tumor surgery, a wound infection requiring surgical treatment (CDG-3b) may not pull down the KPS at discharge so that there is not a linear correlation between CDG and KPS (10). It is therefore remarkable that our results indicate that – at least in CSF shunt surgery - CDG seems to reflect the severity of a complication quite accurately.

Risk factors for the occurrence of a complication

A lower general state of health is a significant risk factor for the occurrence of a subsequent complication (18). To measure the state of health at admission, we

analyzed the clinical status scores, the source of admission and the indication for surgery as potential risk factors for the occurrence of a complication. The analysis of the risk factors is explained in the result section logistic regression.

NPH patients had a lower rate of complications of only 36% compared to 69% of the other patients and usually had their shunt implanted as a first intervention.

Patients with a complication had a lower KPS before and after the complication compared to patients without a complication. This lower KPS at admission could be explained by the different background of patients. Of the cases with a complication, 65% underwent shunt surgery as a secondary intervention. These patients had a lower KPS before shunt surgery due to a trauma, a tumor or a hemorrhage, which made their primary intervention necessary and secondarily led to a hydrocephalus. We found that an inferior KPS score at admission is a significant risk factor for the occurrence of a subsequent complication.

The institution from where patients were admitted was associated with the occurrence of a complication. Most patients that would not experience a complication were admitted to the hospital from routine surroundings (home; 64%), whereas 25% of the patients with a subsequent complication were admitted from another hospital. Therefore, patients admitted to our clinic from another hospital or another department in our hospital carried a significantly higher risk of suffering from a complication, than patients admitted from routine surroundings or other care institutions. It is conceivable that the complexity of the case was higher if patients required in-patient care before transfer to neurosurgery, which eventually translated into a higher complication rate.

Age was not a predictive risk factor for the occurrence of a complication, in line with the NPH patient group having a higher median age.

Limitations of our study

In our study design, most parts of the data were collected prospectively, whereas some data had to be compiled retrospectively from electronic patient records. While the electronic patient records were complete, the data had to be transformed to the scales used in the patient registry.

Classifying the severity of a complication by CDG is therapy-oriented and does not consider the patient's subjective well-being, satisfaction with received treatment or quality of life. A complication may be classified as low-grade, even though it may have a severe impact on the patient. Nevertheless, we observed a strong correlation between CDG grade and functional status (KPS) for our patient group.

Pooling all non-NPH patients into one group entails summarizing the outcome and complications of patients with SAH, TBI, tumors and other pathologies. On the other hand, all these categories are made up of patients who suffer from very severe diseases, which stands in stark contrast to NPH patients, which mostly only suffer from few comorbidities. For this reason, we find it justified to consider the risk of shunt treatment in NPH completely separated from all other indications. The number of patients in this study allows only limited degree of dividing patients into subgroups. To reach relevant conclusions, we decided to use this rather simple differentiation into NPH patients and other indications.

Conclusions

Our study provides a direct comparison of patients with shunts due to NPH and patients with shunts for other indications regarding functional outcome and complication rates and classification of complications. While shunt surgery in general has a high rate of complications in patients with hydrocephalus following hemorrhage, TBI or tumors, this rate was significantly lower for NPH patients, which in general suffer from less comorbidity.

As a secondary finding, CDG seems to be an appropriate tool not only for classifying complications, but also for evaluating the complications' severity.

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Figures and tables

Figure 1. Study profile and patient selection.

A total of 285 shunt-related procedures were performed in our unit. In the reporting period, complete data were available for 195 cases. Among them, 174 (90%) were ventriculoperitoneal (VP) shunt implantations and 23 (11%) were shunt revisions.

Figure 2. Patient age distribution.

The age of normal pressure hydrocephalus (NPH) patients was close to their median (75 years). Other hydrocephalus patients were younger with a median age of 55 years. Shunt revision occurred more frequently with age. Lines were shifted for better visibility.

Figure 3. Functional status is reduced in patients with complications.

Functional performance (KPS) improved within one year after shunting for patients with complications (brown boxes) and without complications (green boxes). The width of the bars reflects the number of patients in each group. Patients who experience a postoperative complication have a lower KPS already at admission. At 24 months follow-up, only patients with complications were seen, which is reflected in the lower median KPS. The analysis of complications was done in the reporting period from discharge to 3 months (3M).

Figure 4. The incidence of complications is lower for NPH.

Complication rates are compared between the three indications for surgery, which are normal pressure hydrocephalus (NPH), other hydrocephalus and revision. The column height is normalized to the number of patients within each group and the column width indicates the relative number of patients in each group. The complication rate is lowest for NPH patients (16/44=36%).

Figure 5. Relative frequency of classes of complications compared for NPH and other hydrocephalus.

Shunt-related complications occurred most often, followed by pneumonia, urinary tract infection and central nervous system (CNS) infection. Normal pressure hydrocephalus (NPH) patients had fewer complications than patients with an occlusive or malresorptive hydrocephalus. Some patients had multiple complications.

Figure 6. The severity of complications is lower for NPH.
The rate of complications with Clavien-Dindo Grade (CDG) >1 were lower for patients with normal pressure hydrocephalus (NPH).

Figure 7. CDG grade correlates with KPS and length of stay.
(A) Distribution of Clavien-Dindo Grades (CDG) of complications at discharge. The majority of complications (56/92 = 61%, 95%-CI [50% 71%]) were treated without invasive treatment (CDG-1 and CDG-2).

(B) The length of stay is prolonged with the CDG of the complication at discharge. The length of stay and the CDG were correlated with Spearman's rho=0.46 (p-value = 0.001) and the linear fit had a slope of 2.5 days per increment of CDG. The median postoperative length of hospitalization was significantly higher in cases with a complication at discharge (9 vs. 4 days, p-value < 0.001, Mann-Whitney U-test).

(C) The KPS at discharge decreases with the CDG of the complication. The KPS and the CDG were correlated with Spearman's rho=-0.48 (p-value < 0.001) and the linear fit had a slope of -7.9 KPS points per increment of CDG. The median KPS at discharge was higher without a complication (no AE, KPS = 75) than with a complication (CDG 1-5, KPS = 40, p-value < 0.001, Mann-Whitney U-test).

519

520 **Table 1. Clavien-Dindo Grade (CDG) of complications and the time of**
521 **occurrence.**

522 In patients where more than one complication occurred, only the worst CDG is listed
523 for ease of handling. CI = confidence interval.

CDG	Discharge	6 weeks	3 months	Surgery until 3 months	95% - CI
1	12	3	1	14 (7%)	4% - 12%
2	44	7	4	46 (24%)	18%-30%
3a	4	0	1	5 (3%)	1%-6%
3b	23	9	9	39 (20%)	15%-26%
4a	5	0	0	4 (2%)	0%-3%
4b	0	0	1	1 (1%)	0%-3%
5	4	1	0	5 (3%)	1%-6%
total	92	20	16	114 (58%)	51%-65%

524

525 **Table 2. Shunt-related complications and Clavien-Dindo Grade (CDG).**

Complication	CDG				n
	1	2	3a	3b	
overdrainage	11	2	1	6	20
underdrainage	2	-	-	1	3
infection	1	-	-	8	9
abdominal dislocation	-	-	-	6	6
blocking	-	-	-	5	5
disconnection	1	-	-	1	2
total	15	2	1	27	45

526

Table 3. Logistic regression

In case of continuous predictors, the odds ratio (OR) indicates the change of risk if the predictor changes by one unit. In case of categorical predictors, the OR indicates the change of risk if the predictor changes from the reference level (indicated after "vs.") to the mentioned level (indicated in front of "vs."). The group other hydrocephalus and a lower Karnofsky Performance Status (KPS) at admission are associated with a higher risk for a complication. CI = confidence interval.

	Compared categories	Odds ratio (OR) for complication	95% - CI	p-value
Intercept		5.13	1.035-27.378	0.049
age		1	0.986-1.03	0.501
indication	NPH vs. other hydrocephalus	0.312	0.125-0.757	0.011
indication	Revision vs. other hydrocephalus	0.477	0.163-1.33	0.163
sex	Female vs male	1.472	0.778-2.813	0.237
KPS at admission		0.974	0.959-0.989	0.001

Figure1

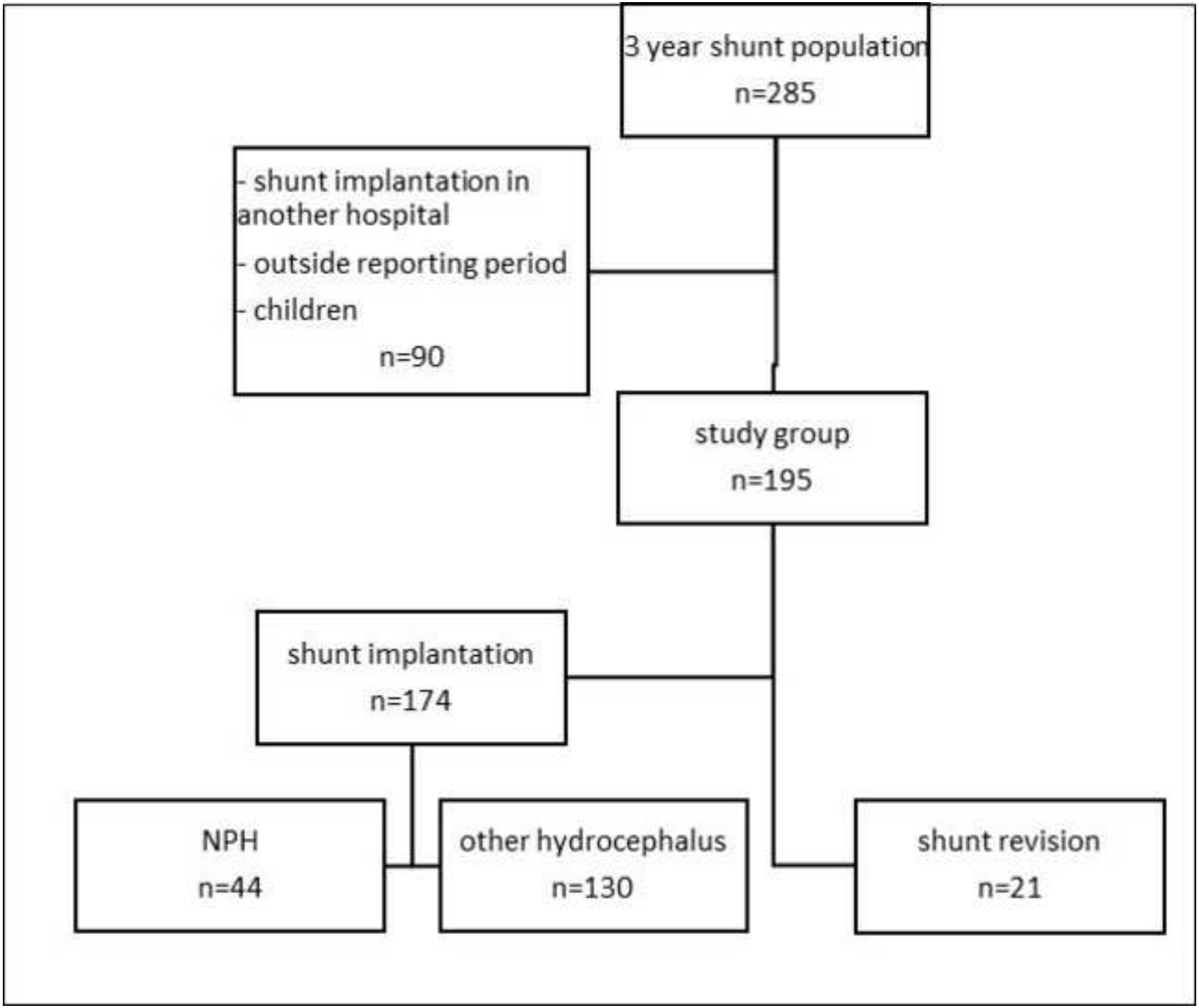

3 year shunt population
n=285
- shunt implantation in another hospital
- outside reporting period
- children
n=90
study group
n=195
shunt implantation
n=174
NPH
n=44
other hydrocephalus
n=130
shunt revision
n=21

Figure 2

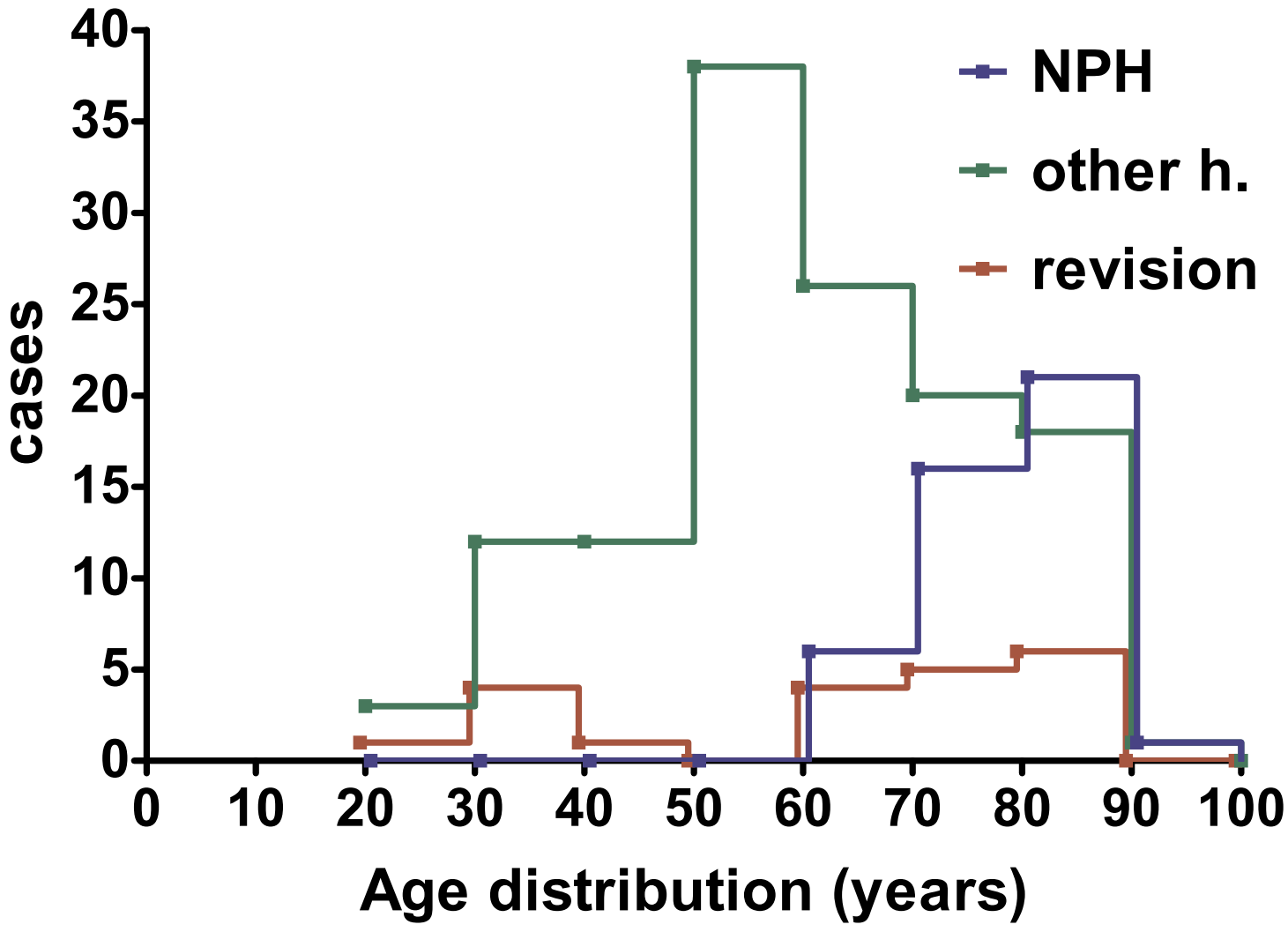

40
35
30
25
20
15
10
5
0
cases
0
10
20
30
40
50
60
70
80
90
100
Age distribution (years)
NPH
other h.
revision

Figure 3

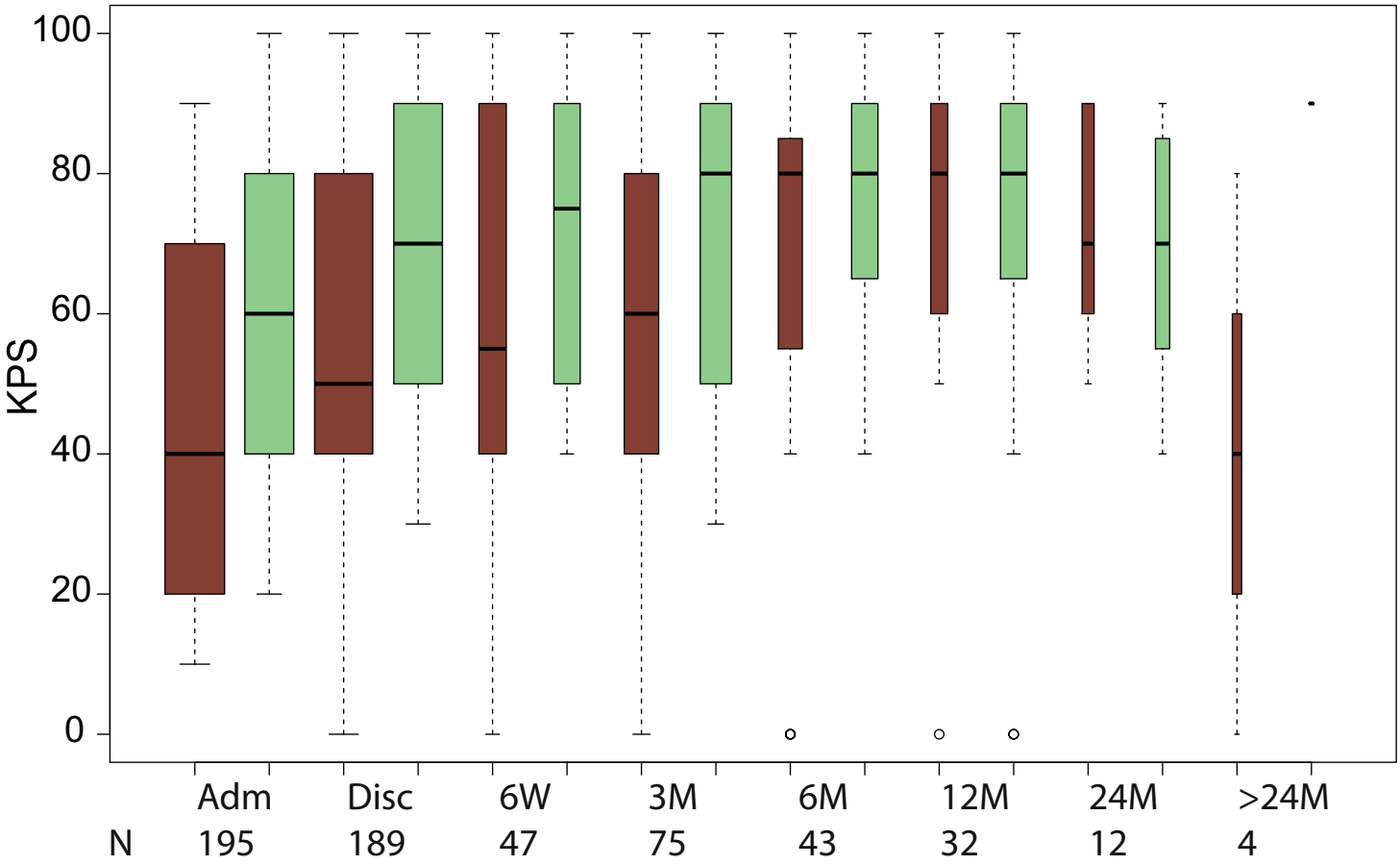

100
80
60
40
20
0
KPS
Adm
Disc
6W
3M
6M
12M
24M
>24M
N
195
189
47
75
43
32
12
4

Figure 4

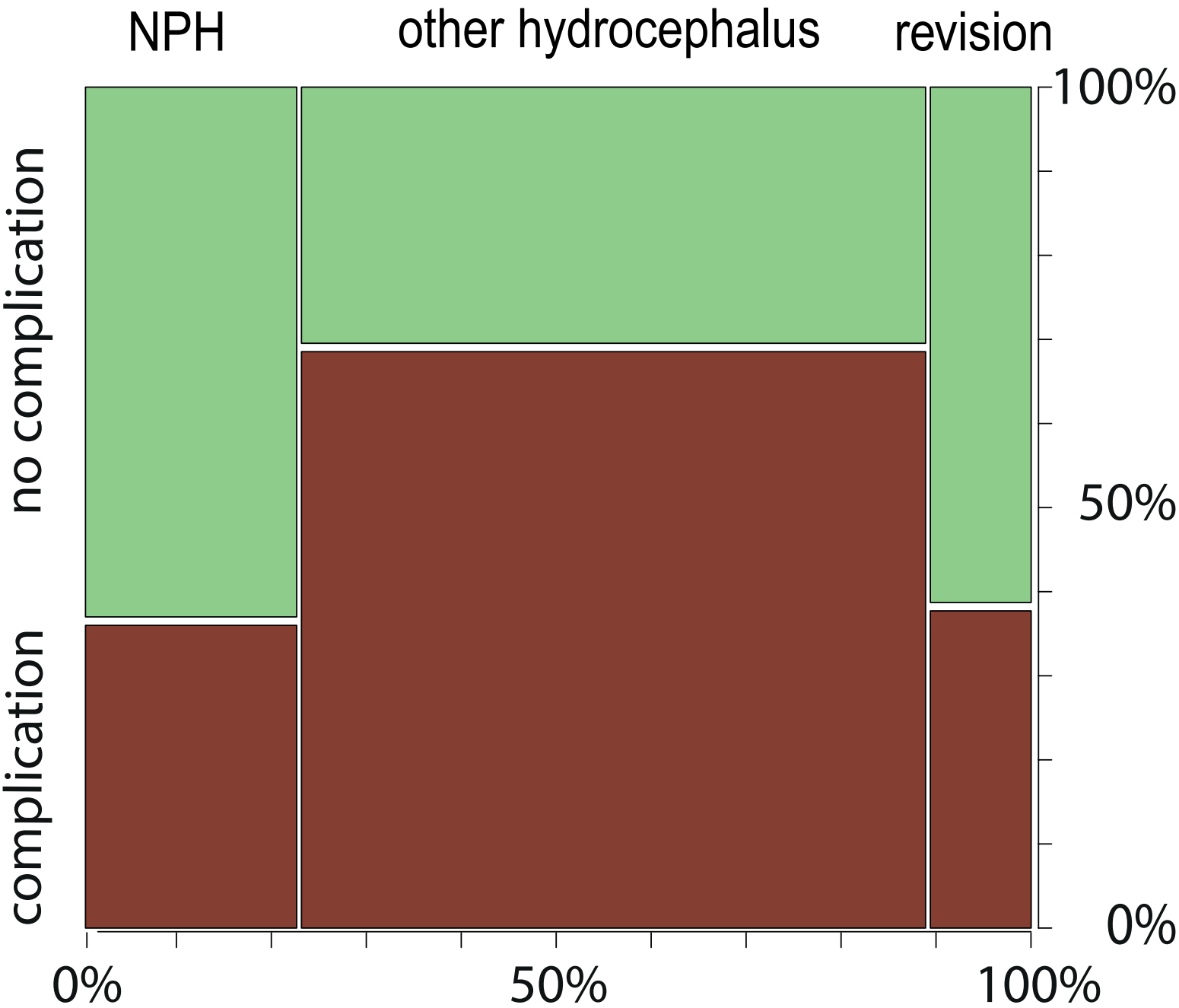

NPH
other hydrocephalus
revision
no complication
complication
100%
50%
0%
0%
50%
100%

Figure 5

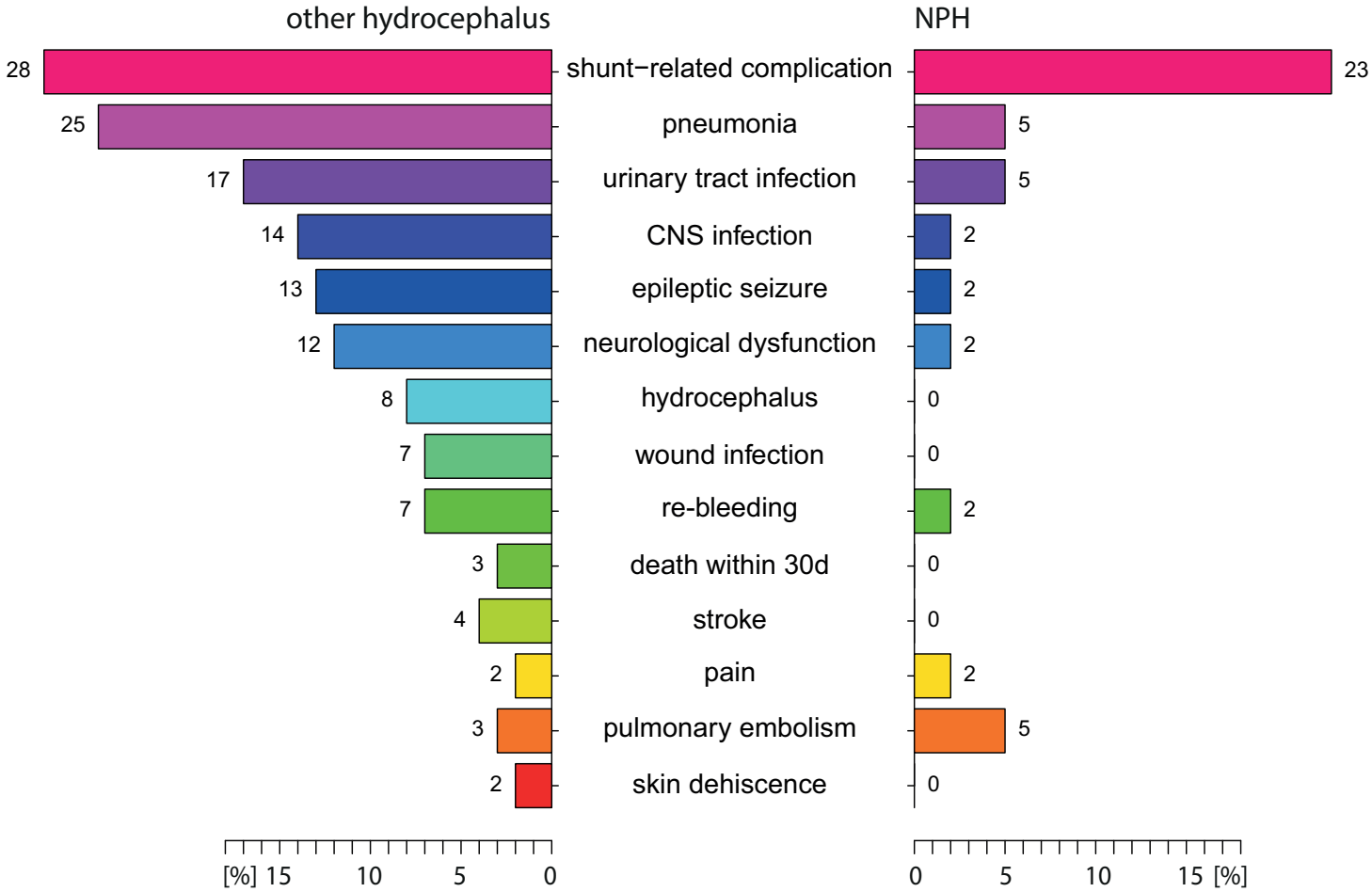

other hydrocephalus
NPH
28
shunt−related complication
23
25
pneumonia
5
17
urinary tract infection
5
14
CNS infection
2
13
epileptic seizure
2
12
neurological dysfunction
2
8
hydrocephalus
0
7
wound infection
0
7
re-bleeding
2
3
death within 30d
0
4
stroke
0
2
pain
2
3
pulmonary embolism
5
2
skin dehiscence
0
[%] 15 10 5 0
0 5 10 15 [%]

Figure 6

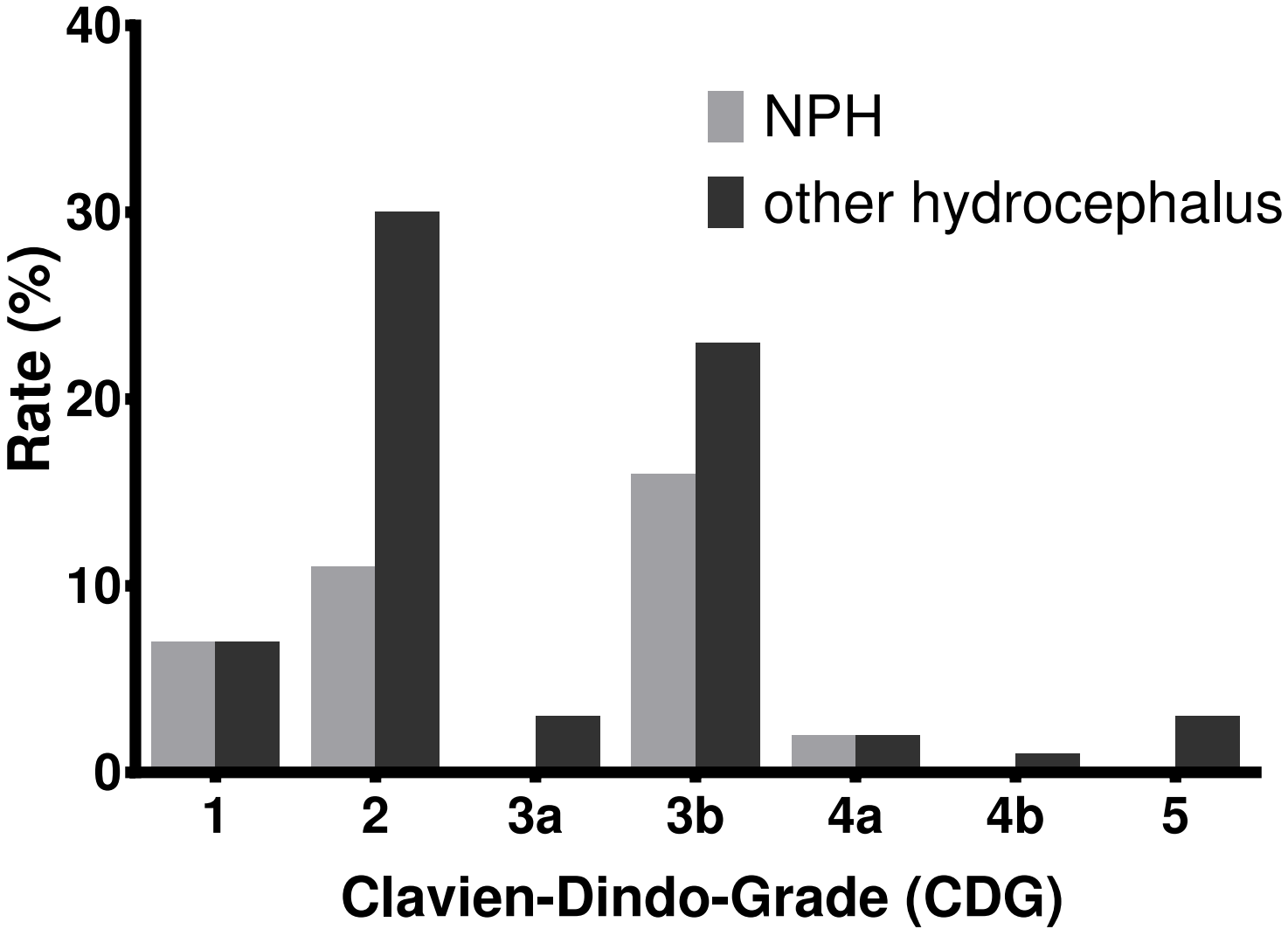
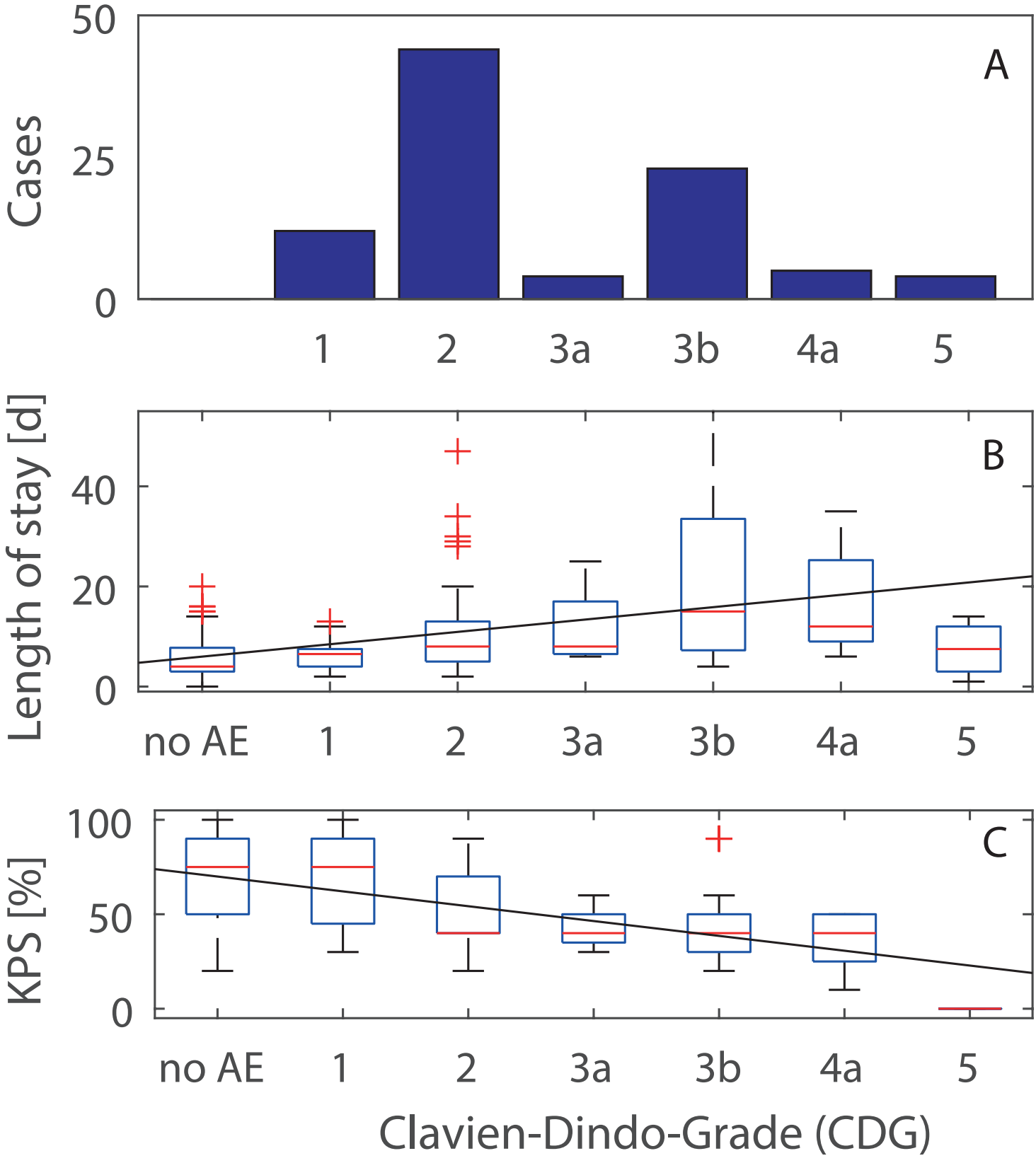

40
30
20
10
0
Rate (%)
NPH
other hydrocephalus
1
2
3a
3b
4a
4b
5
Clavien-Dindo-Grade (CDG)

Figure 7


A
Cases
50
25
0
1
2
3a
3b
4a
5
B
Length of stay [d]
40
20
0
no AE
1
2
3a
3b
4a
5
C
KPS [%]
100
50
0
no AE
1
2
3a
3b
4a
5
Clavien-Dindo-Grade (CDG)